Tanta University
Faculty of engineering
Electrical Power and Machines engineering department
Energy Conversion Course

Sheet (3) …… Electrical Transformers

1) The no-load current of a transformer is 10 A at a power factor of 0.25 lagging, when connected to 400 V, 50 Hz supply. Calculate:
P.122
   a) Magnetizing component of no-load current.
   b) Iron loss and c) Maximum value of flux in the core assume that primary winding turns are 500.

2) A 15 kVA, 2200/110 V transformer has R_1=1.75 Ω, R_2=0.0045 Ω. The leakage reactances are X_1=2.6 Ω and X_2=0.0075 Ω. Calculate:
P.133 Pri. Sec.
   a) Equivalent resistance referred to primary
   b) Equivalent resistance referred to secondary
   c) Equivalent reactance referred to primary
   d) Equivalent reactance referred to secondary
   e) Equivalent impedance referred to primary
   f) Equivalent impedance referred to secondary
   g) Total cupper loss

3) 250/125 V, 5 kVA single phase transformer has primary resistance of 0.2 Ω and reactance of 0.75 Ω. The secondary resistance is 0.05 Ω and reactance of 0.2 Ω.
P.144
   a) Determine its regulation while supplying full load on 0.8 leading p.f.
   b) The secondary terminal voltage on full load and 0.8 leading p.f.

4) A 4 kVA, 200/400 V, 50 Hz, single phase transformer has equivalent resistance referred to primary as 0.15 Ω. Calculate:
P.148
   a) The total copper loss on full load
   b) The efficiency while supplying full load at 0.9 p.f lagging
   c) The efficiency while supplying half load at 0.8 p.f lagging
   Assume total iron losses = 60 W.

5) A 5 kVA, 500/250 V, 50 Hz, single phase transformer gave the following readings,
P.159
O.C. Test: 500 V, 1 A, 50 W (L.V. side open) → X_m, R_c
S.C. Test: 25 V, 10 A, 60 W (L.V. side shorted) → R_{eq} X_{eq}
Determine:
   a) η % on full load, 0.8 lagging p.f.
   b) The voltage regulation on full load, 0.8 leading p.f.
   c) η % on 60% of full load, 0.8 leading p.f.
   d) Draw the equivalent circuit referred to primary and insert all the values in it.

P.161
6) The O.C. and S.C. tests on a 10 kVA, 125/250 V, 50 Hz, single phase transformer gave the following results:
O.C. Test: 125 V, 0.6 A, 50 W (on L.V. side)
5 S.C. Test: 15 V, 30 A, 100 W (on H.V. side)
Calculate:
a) Copper loss on full load
b) Full load $\eta_{\%}$ at 0.8 leading p.f.
c) Half load $\eta_{\%}$ at 0.8 leading p.f.
d) Regulation at full load, 0.9 leading p.f.

P.171
7) A 2500/250 V, 50 Hz, 50 kVA, single phase transformer has a resistance of 0.8 Ω and 0.012 Ω and a reactance of 4 Ω and 0.04 Ω for H.V. and L.V. windings respectively. Transformer gives 96% maximum efficiency at 75% full load at unity p.f. The magnetizing component of no load current is 1.2 A on 2500 V side. Find out ammeter, voltmeter and wattmeter readings on O.C and S.C. test if supply is given to the 2500 V side in both cases.

Best wishes
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2013/2014

sheet (3) Solution

Problem ①

$I_o = 10\,A$ at $P.f_o = 0.25$ lag , $V_1 = 400\,V$, $f = 50\,Hz$

Calculate:

① I_m ② Iron loss ③ Max. value of flux in the core if $N_1 = 500$

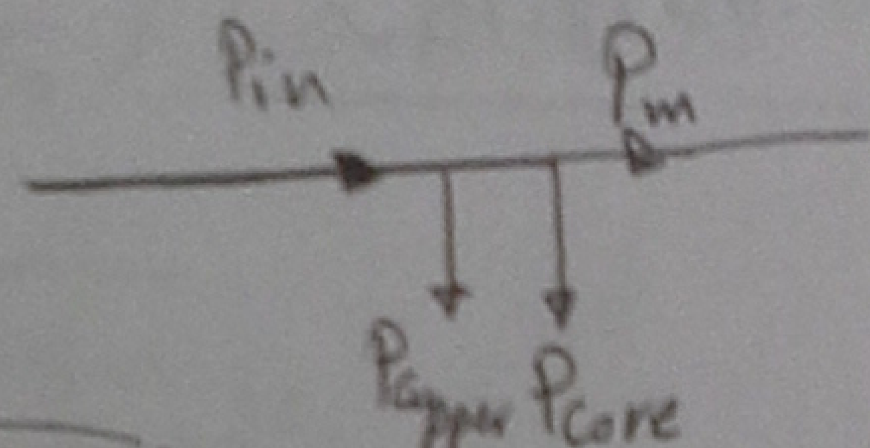
الحل

① $I_m = I_o \sin\phi_o$ $\quad \because P.f_o = \cos\phi_o$

$\phi_o = \cos^{-1}(0.25) = 75.522^\circ$

$\therefore I_m = 10 * \sin(75.522) = \boxed{9.6824\,A}$ #①

② at no-load



$P_{Iron} = V_1 * I_c$

$I_c = I_o \cos\phi_o = \boxed{2.5\,A}$

$\boxed{P_{iron} = 1000\,Watt}$

③ $\phi_m = ?$

$\because E_1 = 4.44\, f\, \phi_m\, N_1$

$400 = 4.44 * 50 * \phi_m * 500$

$\therefore \boxed{\phi_m = 3.6036\,mwb}$

for problem ②

$P_{copper_{sec}} = I_{1_{sec}}^2 * R_t|_{sec} = \left(\frac{15*10^3}{110}\right)^2 * 0.008875 = \boxed{165.031\,watt}$

لابد انهم يكونوا متساويين

or

$P_{copper\,total} = I_1^2 * R_1 + I_2^2 * R_2$

$= \left(\frac{15000}{2200}\right)^2 * 1.75 + \left(\frac{15000}{110}\right)^2 * 0.0045 = \boxed{165.031\,W}$

problem ② 15KVA, 2200/110V, has $R_1 = 1.75\,\Omega$, $R_2 = 0.0045\,\Omega$, ~~x_m~~, $X_2 = 0.0075\,\Omega$

الحل

a) R_t Refered to Primary

$R_1 = 1.75\,\Omega$, $R_2' = 0.0045 * \left(\frac{2200}{110}\right)^2 = 1.8\,\Omega$

الى ذاهب إليه

تربيع ②

الى طالع منه

$\therefore R_t|_{pri} = R_1 + R_2' = \boxed{3.55\,\Omega}$

b) R_t Refered to secondary

$R_2 = 0.0045\,\Omega$, $R_1' = 1.75 * \left(\frac{110}{2200}\right)^2 = \boxed{4.375 * 10^{-3}\,\Omega}$

$\therefore R_t|_{sec.} = 8.875 * 10^{-3} = \boxed{0.008875\,\Omega}$

c) X_t Refered to primary

$X_1 = 2.6\,\Omega$, $X_2' = 0.0075 * \left(\frac{2200}{110}\right)^2 = 3\,\Omega$

$\therefore X_t|_{prim} = \boxed{5.6\,\Omega}$

d) X_t Refered to secondary

$X_2 = 0.0075\,\Omega$, $X_1' = 2.6 * \left(\frac{110}{2200}\right)^2 = 6.5 * 10^{-3}\,\Omega$

$\therefore X_t|_{sec} = \boxed{0.014\,\Omega}$

e) Z_t Ref. to primary

$Z_t|_{prim} = \sqrt{(R_t|_{prim})^2 + (X_t|_{prim})^2} = \boxed{6.6304\,\Omega}$

f) Z_t Ref. to secondary

$Z_t|_{sec.} = \sqrt{(R_t|_{sec})^2 + (X_t|_{sec.})^2} = \boxed{0.01657\,\Omega}$

e) total Copper loss

$P_{copper\,prim} = I_{1\,prim}^2 * R_t|_{prim} = \left(\frac{15 * 10^3}{2200}\right)^2 * 3.55 = \boxed{165.031\text{ watt}}$

check ملزمتي مسألة ① اثبات رقم

Exm ③ 250/125 V XFMR , $S = 5KVA$, $1-\phi$, $R_1 = 0.2\Omega$, $X_1 = 0.75\Omega$
$R_2 = 0.05\Omega$, $X_2 = 0.2\Omega$

① Regulation for full load on 0.8 P.f lead

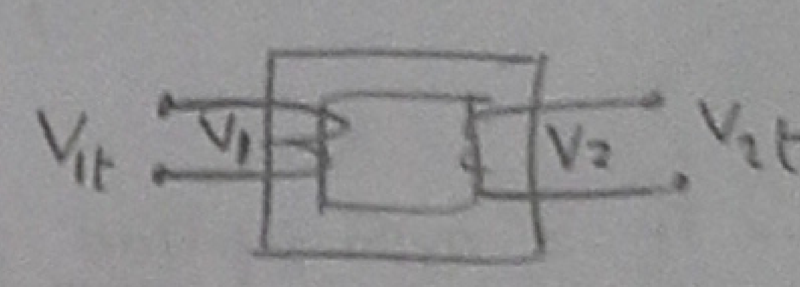
② V_2 on full load and 0.8 P.f lead

حل

$R_1 = 0.2\Omega$, $X_1 = 0.75\Omega$, $R_2 = 0.05\Omega$, $X_2 = 0.2\Omega$, $\cos\phi = 0.8$ leading

① → Refered to secondary.

$$R_1' = \cancel{R_1} * \left(\frac{125}{250}\right)^2 = 0.05\Omega \quad (R_1 = 0.2)$$



$$\therefore Rt_{sec.} = 0.05 + 0.05 = \boxed{0.1\Omega}$$

$$X_1' = \cancel{X_1} * \left(\frac{125}{250}\right)^2 = 0.1875\Omega \quad (X_1 = 0.75)$$

$$\therefore Xt|_{sec} = \boxed{0.3875\Omega}$$

$$I_{sec.} = \frac{S}{V_{sec.}} = \frac{5*10^3}{125} = \boxed{40A} = I_2$$

$$\%R = \frac{I_2 Rt_{sec.} \cos\phi \pm I_2 Xt_{sec.} \sin\phi}{V_2} * 100$$

+ → Lag P.f
− → lead P.f

$$\phi = \cos^{-1}(0.8) = 36.869°$$

$$\therefore \sin\phi = 0.6$$

Lead سالب

$$\therefore \%R = \frac{40 * 0.1 * 0.8 - 40 * 0.3875 * 0.6}{125} * 100 = -4.88\%$$

② the same load

$$\%R = \frac{V_2 - V_{2t}}{V_2} \Rightarrow -4.88 = \frac{125 - V_{2t}}{125}$$

V_{2t} → terminal voltage

$$\therefore \boxed{V_{2t} = 131.1V}$$

leading لأن $V_2 < V_{2t}$ لأن الاشارة سالبة
(2 [illegible])

problem ④ $S = 4KVA$, $200/400V$, $50Hz$ XFMR, $1-\phi$

$R_{t_{prim}} = 0.15\Omega$, iron loss $= 60W$

① P_{copper} total on full load

② η full-load at 0.9 P.f lag

③ η half-load at 0.8 P.f lead

الحل

$V_1 = 200V$, $V_2 = 400V$, $R_{t_{pr}} = 0.15$, $P_i \Rightarrow$ or $P_{core} = 60W$

①

$\therefore R_{t_{sec.}} = 0.15 * \left(\frac{400}{200}\right)^2 = \boxed{0.6\Omega}$ Refered to secondary

$I_{2_{f.L}} = \frac{S}{V_2} = \frac{4000}{400} = 10A$

$\therefore P_{copper} = I_{2_{f.L}}^2 * R_{t_{sec.}} = 10^2 * 0.6 = \boxed{60W}$ # or

$P_{copper} = I_{1_{f.L}}^2 R_{t_{prim}}$

$\left(\frac{4000}{200}\right)^2 * 0.15 = 60W$

② $\therefore \eta = \frac{S \cos\phi}{S\cos\phi + P_i + P_{copper(f.L)}}$

$\therefore \eta$ at $\cos\phi = 0.9$ lag (full-load)

$\therefore \eta = \frac{4 * 10^3 * 0.9}{4 * 10^3 * 0.9 + 60 + 60} * 100 = 96.77\%$

③ when the load reduced to half

$n = \frac{\text{actual load}}{\text{full load}}$ = fraction by which load is less than full-load

وعندما يزداد التحميل يتغير (يقل) التيار بنفس النسبة

وبالتالي P_{copper} وأيضاً الـ $P_{out} \leftarrow V_2 I_2 \cos\phi$ تقل بنفس النسبة

$\therefore I_{2_{new}} = n I_{2_{f.L}}$, also $P_{copper_{new}} = n^2 P_{copper_{(f.L)}}$, $P_{out_{new}} = n P_{out_{(f.L)}}$

$\therefore \eta = \frac{n * S * \cos\phi}{n * S * \cos\phi + P_i + n^2 P_{copper_{(f.L)}}} = \frac{0.5 * 4 * 10^3 * 0.8}{0.5 * 4 * 10^3 * 0.8 + 60 + (0.5^2) * 60}$

$\boxed{\therefore \eta = 95.52\%}$

④

Problem ⑤ 5KVA, 500/250 V, 1-ϕ 50 Hz

O.C. Test: 500V, 1A, 50W (L.V. side open)

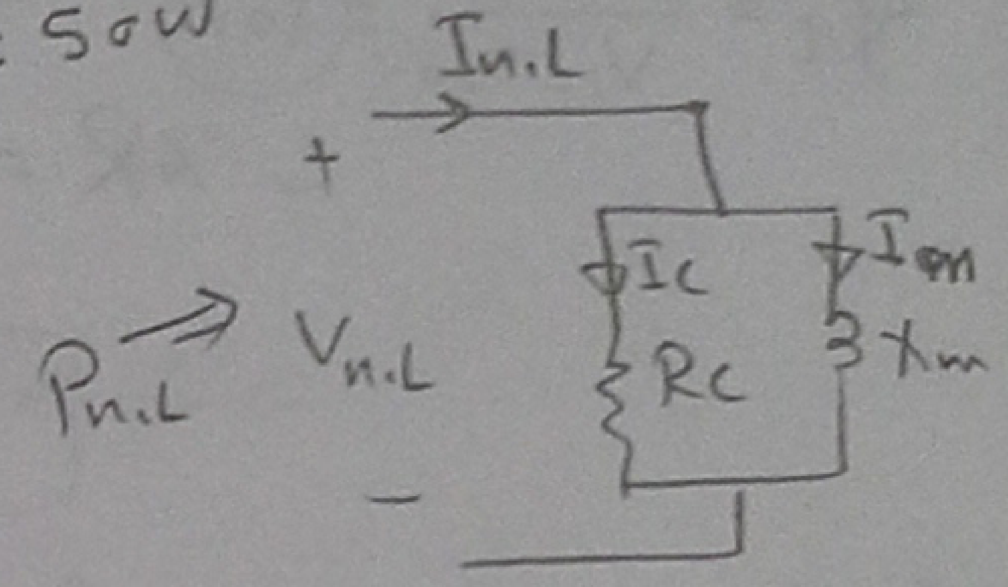
S.C. Test: 25V, 10A, 60W (L.V. side shorted)

① $\eta|_{\text{Full-load, 0.8 lag P.f}}$ ② $\%R_{f.L, 0.8\ P.f\ lead}$ ③ η at 60% of f.L, 0.8 lead P.f

④ Draw Equ. cct ref. to primary with full data.

ملاحظة ← الاختبار o.c تم عند الـ H.V side اللي هو prim وهنا (الحل): النتائج تكون منسوبة للـ primary

→ from O.C. Test $V_{n.L} = 500\,V,\ I_{n.L} = 1\,A,\ P_{n.L} = 50\,W$



$I_c = I_{n.L} \cos\phi_{n.L}$

$I_m = I_{n.L} \sin\phi_{n.L}$

where

$$\cos\phi_{n.L} = \frac{P_{n.L}}{V_{n.L}\, I_{n.L}} = \frac{50}{500 \times 1} = 0.1$$

$$\therefore \boxed{I_c = 0.1\,A} \longrightarrow \therefore R_c = \frac{V_{n.L}}{I_c} = \frac{500}{0.1} = \boxed{5000\,\Omega}$$

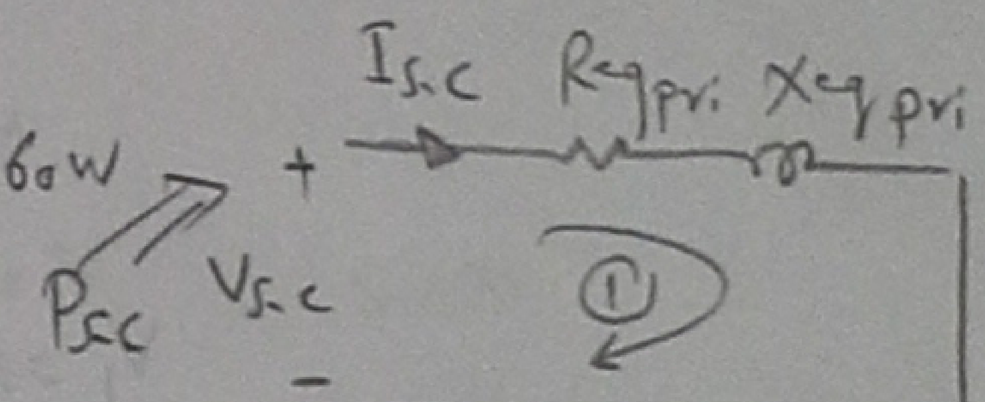
$\phi_{n.L} = \cos^{-1}(0.1) = 84.26$

$\therefore \sin\phi_{n.L} = 0.99498$

$$\therefore \boxed{I_m = 0.9949\,A} \longrightarrow X_m = \frac{V_{n.L}}{I_m} = \frac{500}{0.9949} = \boxed{502.52\,\Omega}$$

at o.c Test $P_{n.L} = P_{core} = P_{iron\ loss} = 50\,W$

→ from s.c Test $V_{s.c} = 25\,V,\ I_{s.c} = 10\,A,\ P_{s.c} = 60\,W$



$\because P_{s.c} = I_{s.c}^2 \times R_{eq\,pri} = P_{copper\,(f.L)}$

$$\therefore R_{eq\,pri} = \frac{P_{s.c}}{I_{s.c}^2} = \frac{60}{(10)^2} = \boxed{0.6\,\Omega}$$

اقدر اقول أن $P_{copper\ f.L}$ لو كان $I_{f.L} = I_{s.c}$ وهو هنا بيساوي صدفة لكن عكس الاسارية

$$I_{f.L} = \frac{5 \times 10^3}{500} = 10\,A$$

from Loop ①

$V_{s.c} = I_{s.c}(R_{eq\,pr} + j X_{eq\,pr}) = Z_{eq} \times I_{s.c}$

$$\therefore Z_{eq} = \frac{V_{s.c}}{I_{s.c}} = \frac{25}{10} = 2.5\,\Omega$$

$$X_{eq\,pr} = \sqrt{Z_{eq}^2 - R_{eq}^2} = \boxed{2.4269\,\Omega}$$

① $\eta_{f.L, 0.8\,pf}$ $\quad \therefore \eta = \dfrac{S * \cos\phi_{f.L}}{S * \cos\phi_{f.L} + P_i + P_{cu\,f.L}} * 100$

$\therefore \eta = \dfrac{5*10^3 * 0.8}{5*10^3*0.8 + 50 + 60} * 100 = \boxed{97.32\%}$

② $\%R_{f.L, 0.8\,pf}$ $\quad \therefore \%R = \dfrac{I_{1f.L} R_{tpri} \cos\phi - I_{1f.L} X_{tpr} \sin\phi}{V_1} * 100$ $\quad \sin\phi \rightarrow 0.6$

$I_{1f.L} = \dfrac{5*10^3}{V_1 = 500} = \boxed{10A}$

$\therefore \%R = \dfrac{10*0.6*0.8 - 10*2.4269*0.6}{500} * 100$

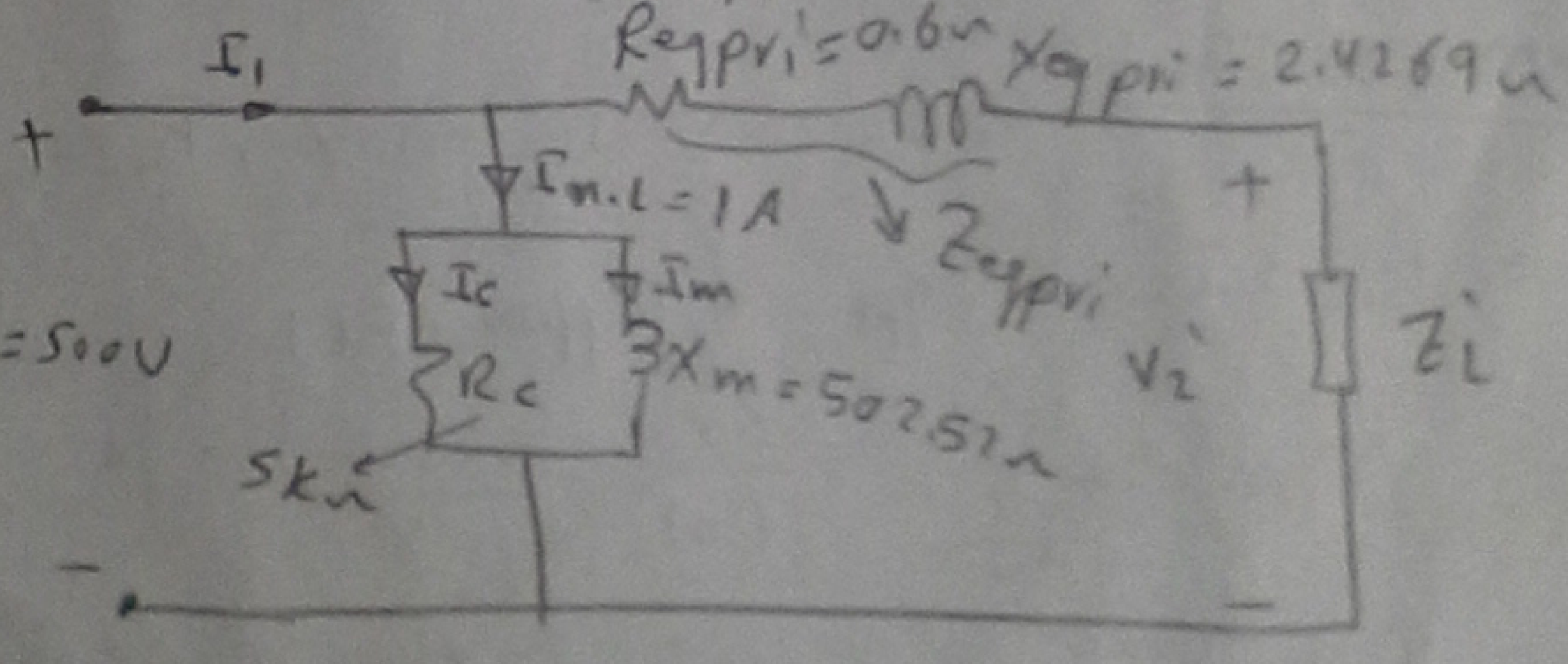
$\therefore \boxed{\%R = -1.95\%}$

③ $\eta_{60\% f.L, 0.8\,pf\,lead}$ $\quad n = \dfrac{60\%}{100\%} = 0.6$

$\therefore \eta = \dfrac{0.6*5*10^3*0.8}{0.6*5*10^3*0.8 + 50 + (0.6)^2*60} * 100$

$\boxed{\therefore \eta = 97.103\%}$

④ Eqn. CKT Refered to primory using approximately Eqn. ckt



#

problem ⑥ like ⑤ but $P_{copper(f.L)}$ should be Calculated

Ex 7 ١٧ 2500/250 V, 1-ϕ, 50 Hz, 50 KVA = S

$R_1 = 0.8\,\Omega$, $R_2 = 0.012\,\Omega$, $X_1 = 4\,\Omega$, $X_2 = 0.04\,\Omega$

$\eta_{max} = 96\%$ at 75% f.L at P.f = 1 = $\cos\phi$

$I_m = 1.2A$ on 2500 V side

Req: O.C. Test, S.C. Test Readings if supply is given to 250V for both cases

اولا

→ Refer parameters to H.V side (primary)

$R_{1eq} = R_1 + R_2' = 0.8 + 0.012\left(\frac{2500}{250}\right)^2 = 2\,\Omega$

$X_{1eq} = X_1 + X_2' = 4 + 0.04\left(\frac{2500}{250}\right)^2 = 8\,\Omega$

→ for max. η $P_{iron\,core} = P_{copper}$ $\therefore P_i = P_{cu}$

$\eta_{max} = \frac{n * S * \cos\phi}{n * S * \cos\phi + 2P_i} * 100$, $n = \frac{75\%}{100\%} = 0.75$

$\therefore 0.96 = \frac{0.75 * 50 \times 10^3 * 1}{0.75 * 50 \times 10^3 * 1 + 2P_i}$

$\therefore P_i = 781.25\,W$ → P_{iron} ⇒ Core loss

→ for O.C test, $V_{n.L}$, $I_{n.L}$, $P_{n.L}$

the applied voltage is rated $\therefore V_{n.L} = V_1 = 2500V$

$P_{n.L} = P_{iron} = 781.25W$

① ← $\boxed{I_m = 1.25 = I_{n.L} \sin\phi_{n.L}}$ → $P_{n.L} = V_{n.L} I_{n.L} \cos\phi_{n.L}$

② ← $\boxed{I_{n.L} \cos\phi_{n.L} = 0.3125}$ $\therefore \cos\phi_{n.L} I_{n.L} = \frac{P_{n.L} = P_{iron}}{V_{n.L}}$

$\frac{1.25}{0.3125} = \frac{I_{n.L} \sin\phi_{n.L}}{I_{n.L} \cos\phi_{n.L}}$ بقسمة العلاقتين

$\therefore \tan\phi_{n.L} = 3.84$ $\therefore \phi_{n.L} = 75.4°$

$\therefore I_{n.L} = \frac{0.3125}{\cos(75.4)} = \boxed{1.239\,A}$

∴ The open circuit readings are

$V_{n.L} = 2500V$, $I_{n.L} = 1.239 A$, $P_{n.L} = 781.25W$

→ for the s.c Test $V_{s.c}$, $I_{s.c}$, P_{copper}

$$I_{1f.L} = I_{s.c} = \frac{S}{V_1} = \frac{50*10^3}{2500} = 20A$$

$$P_{copper\,f.L} = I_{1f.L}^2 * R_{1eq} = 20^2 * 2 = 800W$$

$$Z_{1eq} = \sqrt{R_{1eq}^2 + X_{1eq}^2} = \sqrt{2^2 + 8^2} = 8.2462\,\Omega$$

$$\because Z_{1eq} = \frac{V_{s.c}}{I_{s.c}} \quad \therefore V_{s.c} = Z_{1eq} * I_{s.c}$$

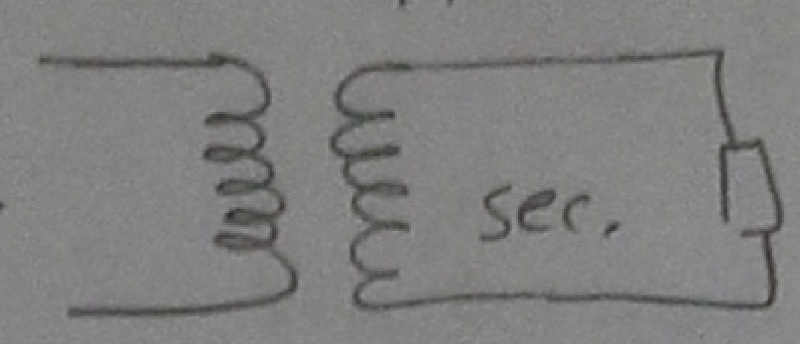
$$\therefore V_{s.c} = 164.924V$$

∴ The short circuit readings are

$V_{s.c} = 164.924V$, $I_{s.c} = 20A$, $P_{s.c} = 800W$ #

① أول مسألة في الكتاب

220 440



$R_{eq} = 0.02\,\Omega$ (prim) step up $V_L = 440V$ 0.8 lag $P_L = 3\,KW$

$X_{eq} = 0.2\,\Omega$

P_{core}

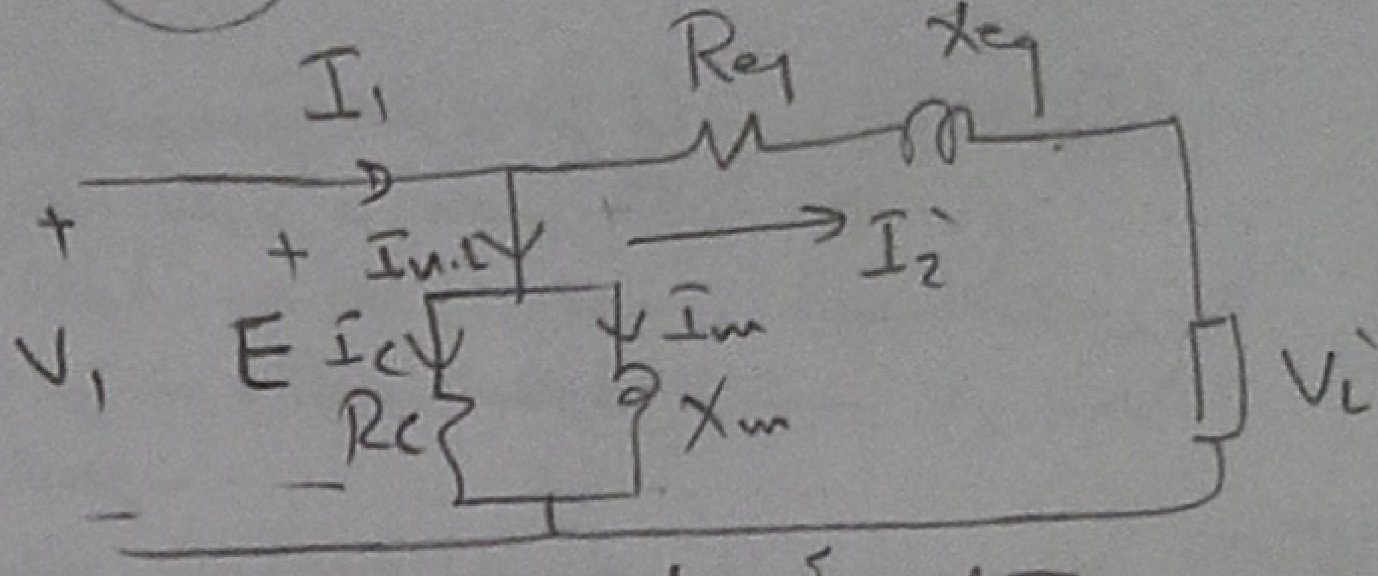
O.C. at primary $V_{n.L} = 220V$, $I_{n.L} = 1.8A$, $P_{n.L} = 39.6W$

R_{eq}, η , %V_R

الحل

$V_L' = \cancel{V_L} * \left(\frac{220}{440}\right) = 220V$

$\boxed{V_L' = 220\angle 0\ V}$



approximate Eq. CKT
ref. to primary

$I_2' = \frac{P_L}{V_L'\ P.f.} = \frac{3000}{220 * 0.8}$

$\therefore I_2' = 17.045\angle -36.87^\circ\ A$

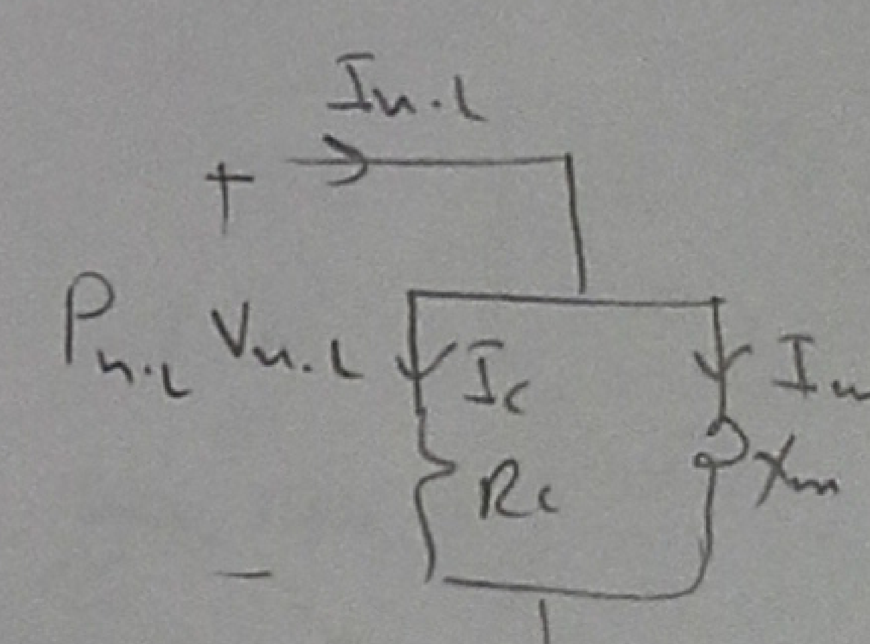
$V_1 = E = I_2'(R_{eq} + jX_{eq}) + V_L' = 17.045\angle -36.87^\circ * (0.02 + j0.2) + 220\angle 0$

$\boxed{V_1 = E = 222.3324\angle 0.65^\circ\ V}$

$I_1 = I_{n.L} + I_2'$

$\downarrow$

$\frac{E}{Z_{n.L}} \rightarrow \left(\frac{R_c\, x_m}{R_c + X_m}\right)$



$I_c = I_{n.L} \cos\phi_{n.L}$ 0.18

$I_m = I_{n.L} \sin\phi_{n.L} = 1.791$

$\cos\phi_{n.L} = \frac{P_{n.L}}{V_{n.L} I_{n.L}} = 0.1$

$\therefore \phi_{n.L} = 84.26$

$\therefore \sin\phi_{n.L} = 0.9949$

$R_c = \frac{V_{n.L}}{I_c} = 1222.22\,\Omega$

$X_m = \frac{V_{n.L}}{I_m} = 122.836\,\Omega$

$\boxed{Z_{branch} = 122.22\angle 84.261^\circ} = \frac{R_c jX_m}{R_c + jX_m}$

$I_{n.L} * Z_{branch} = E$

$\therefore I_{n.L} = 1.8 \angle -83.611^\circ \; A$

$\therefore I_1 = I_{n.L} + I_2' = 18.34 \angle -41^\circ \; A$

$\therefore P_{in} = V_1 I_1 \cos(\theta_v - \theta_i) = 3046.84 \, W$

$P_{out} = I_2' V_L' \cos(\theta_v - \theta_i) = P_L = 3000 \, W$

$\boxed{\eta = 98.45\%}$

$\%V_R = \frac{V_{n.L} - V_{f.L}}{V_{f.L}} \times 100 = \frac{222.3324 - 220}{220}$

$\boxed{\%V_R = 1.06\%}$